Public

EUVL Exposure Tools for HVM: It's Under (and About) Control

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ASML Director, Research

EUV Litho Workshop Amsterdam – November 2016

ASML at a EUV Source Workshop

- The position of EUV for continuation of advanced lithography solutions:
  More than simply shrink
- EUV Installed base performance:
  Imaging, overlay, defectivity: status and implication
- EUV source architecture, performance and power scaling:
  The beauty of the ASML EUV Source
- Summary

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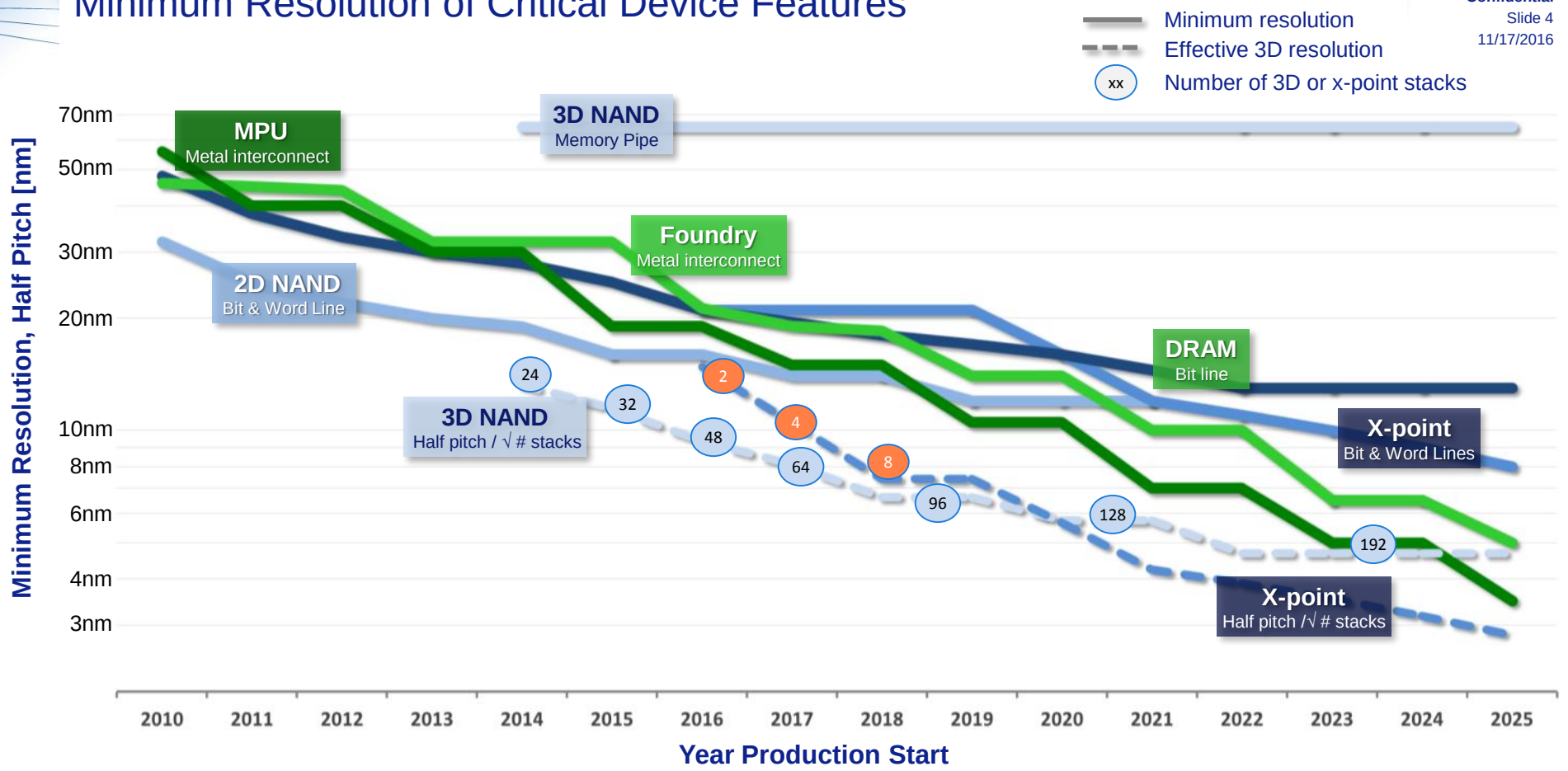
ASML Netherlands B.V., De Run 6501, 5504 DR Veldhoven, The Netherlands

Shrink drives need for advanced lithography solutions…

Minimum Resolution of Critical Device Features



Requirements for Overlay & Focus are “challenging”

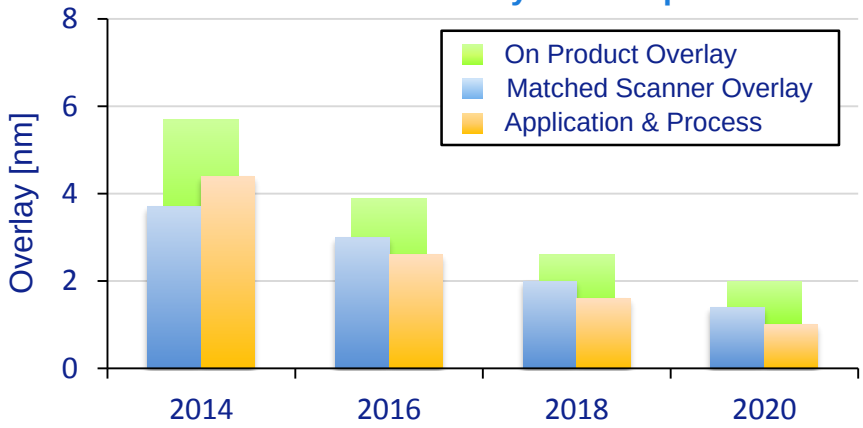
ASML

Year HVM	2014	2015	2016	2017	2018	2019	2020
Logic - Foundry	20 nm	16 – 14 nm		10 nm		7 nm	5 nm
Logic - MPU	22 nm	14 nm		10 nm		7 nm	
DRAM	D2xM	D2xL		D1xH		D1xM	D1x
NAND planar & 3D	19 nm 3D x24	3D x32	16 nm 3D x48	14 nm 3D x64		3D x96	3D x128	x192
X-Point				2x x2		2x x4	1x x4	1x x8
On-Product Overlay[1]	5.0 ~ 4.0 nm	5.0 ~ 3.5 nm	5.0 ~ 3.5 nm	4.5 ~ 2.5 nm	3.5 ~ 2.5 nm	2.5 ~ 2.0 nm	2.5 ~ 1.8 nm
On-Product Focus[2]	90 ~ 60 nm	80 ~ 60 nm	70 ~ 60 nm	60 ~ 50 nm	60 ~ 50 nm	50 ~ 40 nm	50 ~ 40 nm

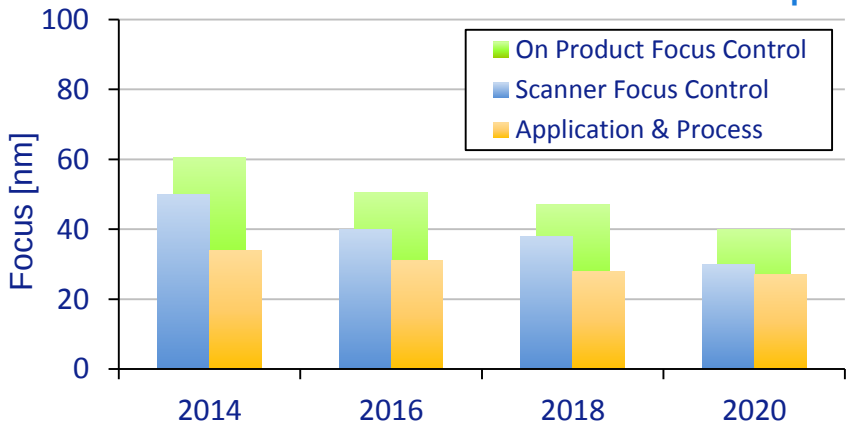
Production
Ramp
R&D
Roadmap

[1] *Range for Logic & Memory critical layers* [2] *Range for EUV & ArF immersion foundry production wafer focus control requirements with process window enhancement techniques.*

Holistic Overlay Roadmap



Holistic Immersion Focus Control Roadmap



ASML's holistic shrink roadmap: DUV-EUV coexistence

Extend DUV to support multiple patterning

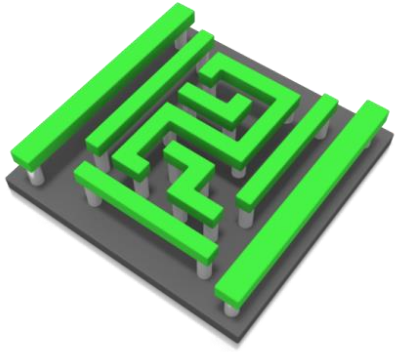
Introduce EUV to volume manufacturing

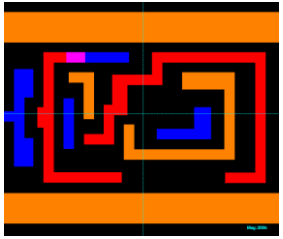
Support both with a suite of process window enhancement, control and calibration products

EUV – Why It Helps

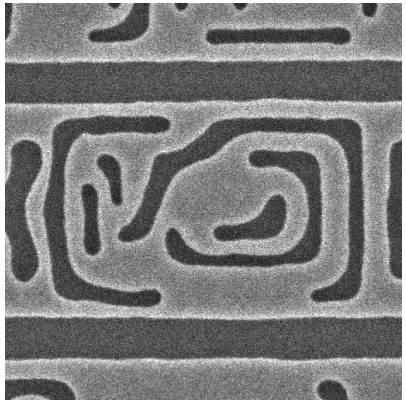
EUV single exposure replaces immersion multiple patterning

*2D-Metal at **32nm pitch** achieved with Quasar illumination*

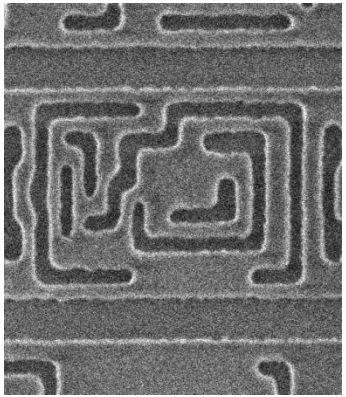




ArFi LE^3
(triple patterning)



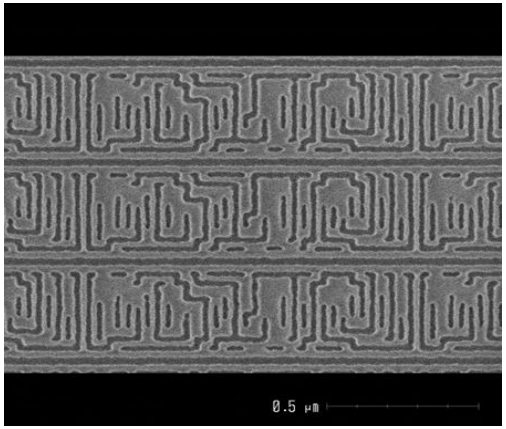
EUV Single Exposure

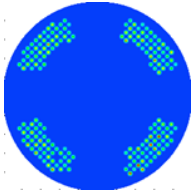


Dose: 20 mJ/cm^2

48nm pitch / 24nm CD

32nm pitch / 16nm CD

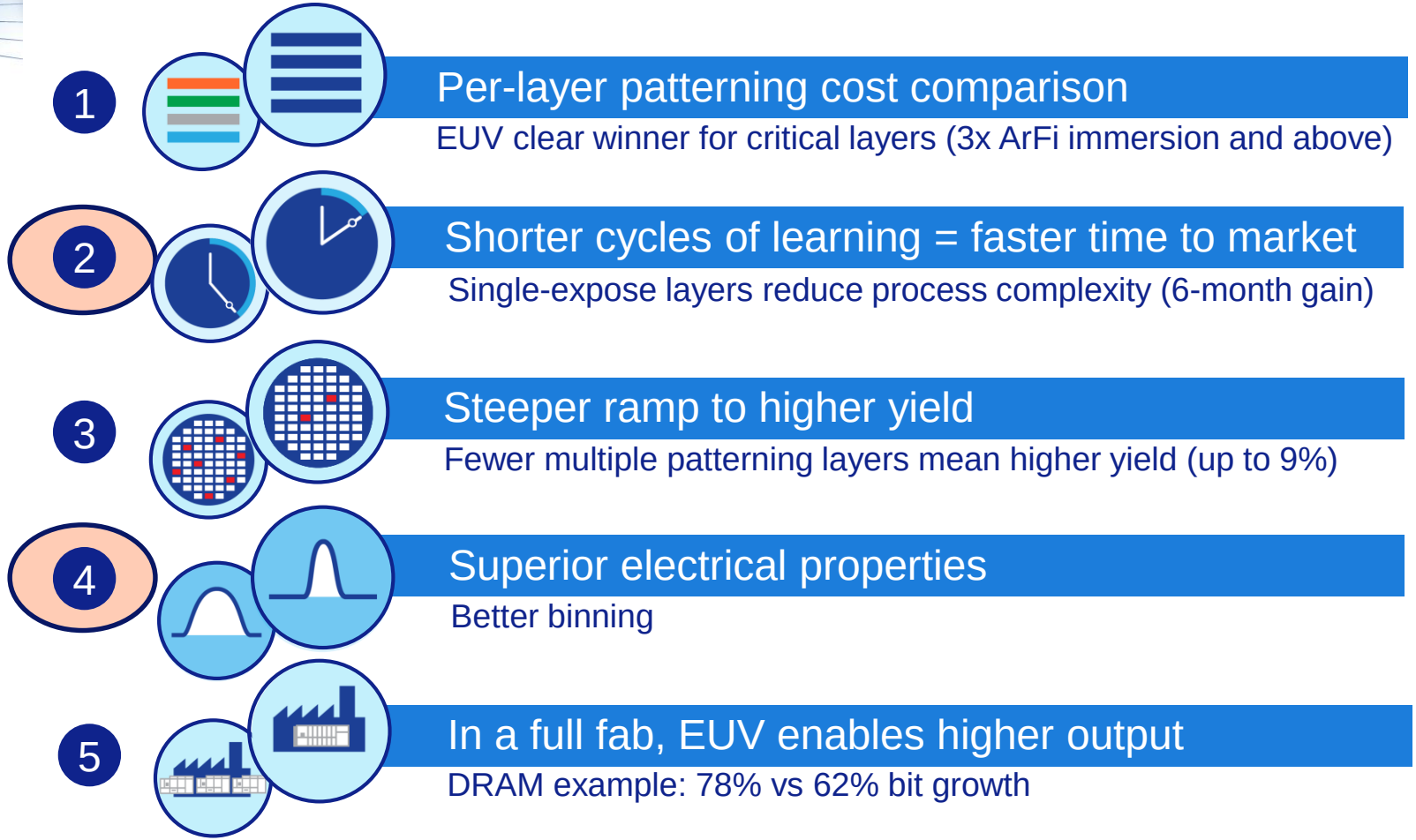




Quasar,
Pupil Fill ratio 20%

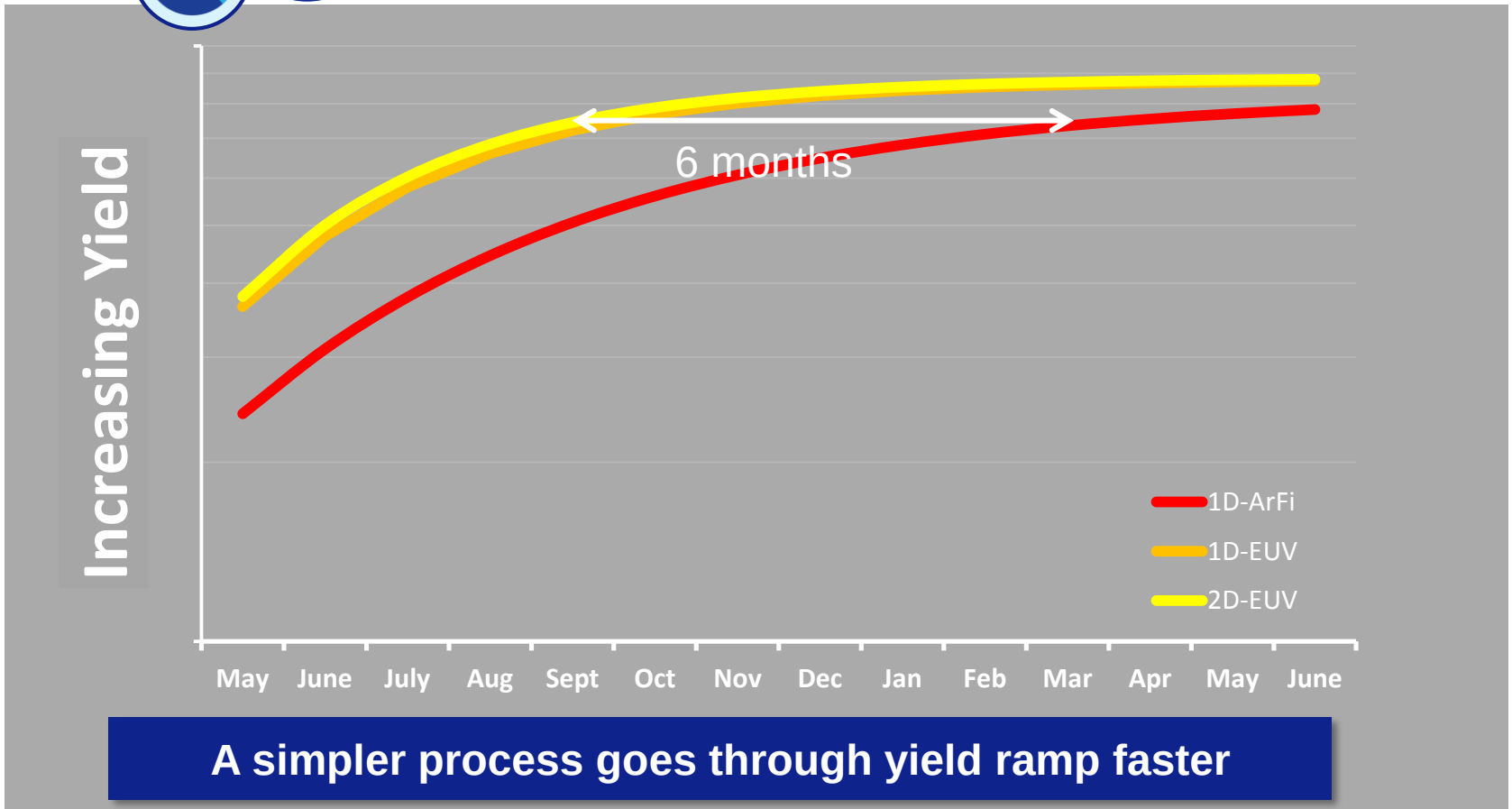
In cooperation with IMEC

EUV: The overall economic value to Customers



1. **Per-layer patterning cost comparison**
   EUV clear winner for critical layers (3x ArFi immersion and above)
2. **Shorter cycles of learning = faster time to market**
   Single-expose layers reduce process complexity (6-month gain)
3. **Steeper ramp to higher yield**
   Fewer multiple patterning layers mean higher yield (up to 9%)
4. **Superior electrical properties**
   Better binning
5. **In a full fab, EUV enables higher output**
   DRAM example: 78% vs 62% bit growth

Faster yield ramp with EUV means faster time to market



A simpler process goes through yield ramp faster

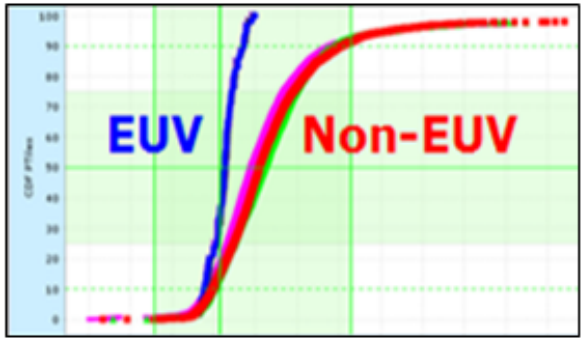
Electrical data confirms: EUV enables superior devices

IBM

Competitive Positioning of EUV

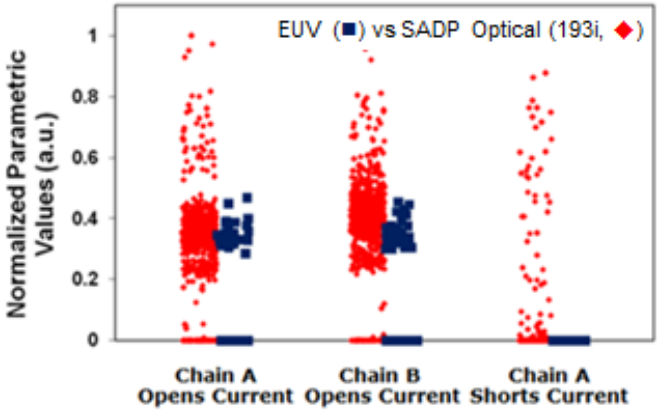
Implication of Improved Variability

EUV v. LE³ 193i
Cumulative Distribution of Wire Resistance



EUV exhibits tighter distribution in resistance than multi-patterning.

EUV v. SADP
Normalized Current for Via Chain



The improved variability of EUV Trench v. SADP Trench is evident in chain distribution and yield.

SADP: Self aligned double patterning

Source: J. Shearer, et al., 61st AVS Symposium

EUV – Where are we now

Customer Confidence in EUV continues to increase

Source power

- 125W configuration at customer sites
- 210 Watts of dose-controlled EUV power demonstrated

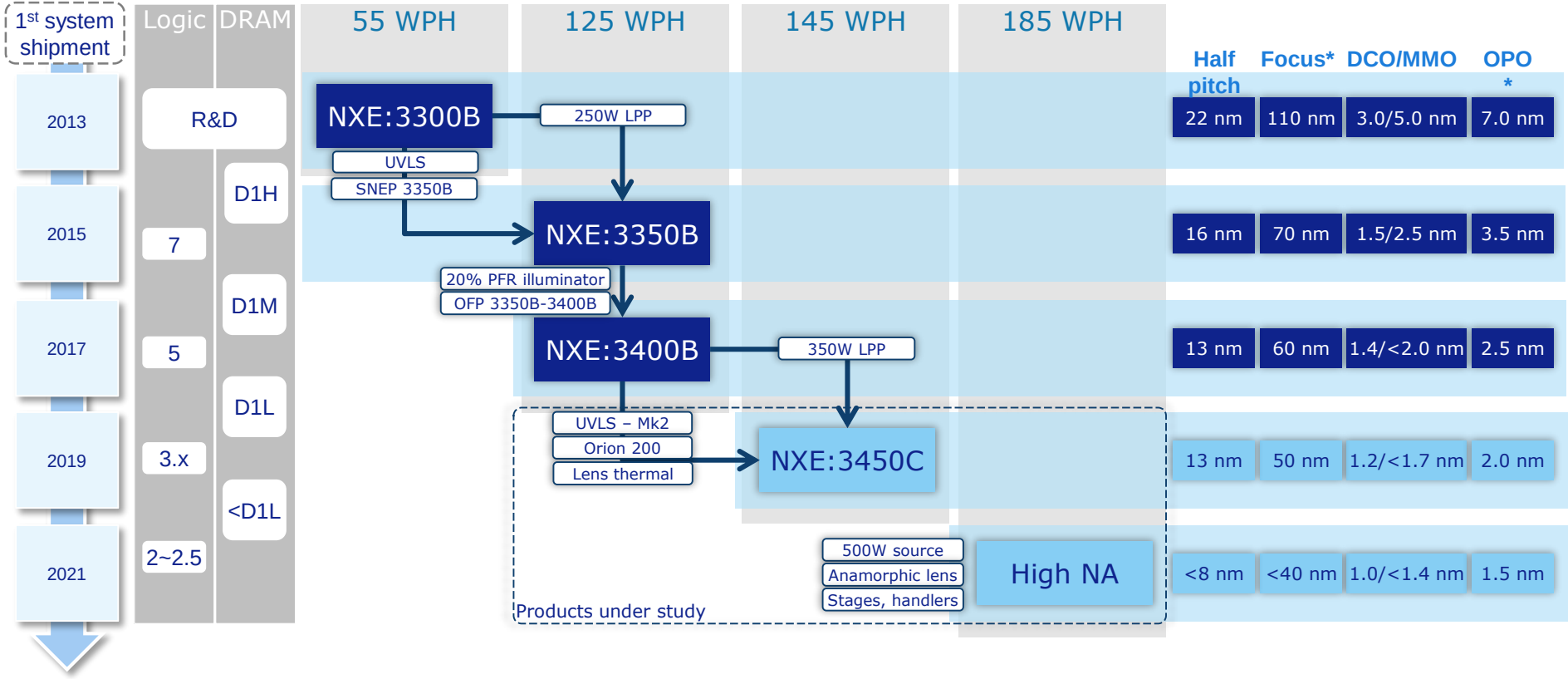
Availability

- Five customer systems have achieved a four-week average availability of more than 80%; however, consistency still needs to be improved

Productivity

- More than 1,200 wafers per day (wpd) exposed on NXE:3350B at a customer site
- Peak performance near target of 1500 wpd (achieved 1488 wpd at ASML)

NXE extension roadmap to optimize capital efficiency



Roadmap: July 2016

** On product overlay (OPO) and focus are not ATP specs, but required performance for specific customer nodes to be achieved including Application and DUV configuration*

EUV – Installed Base

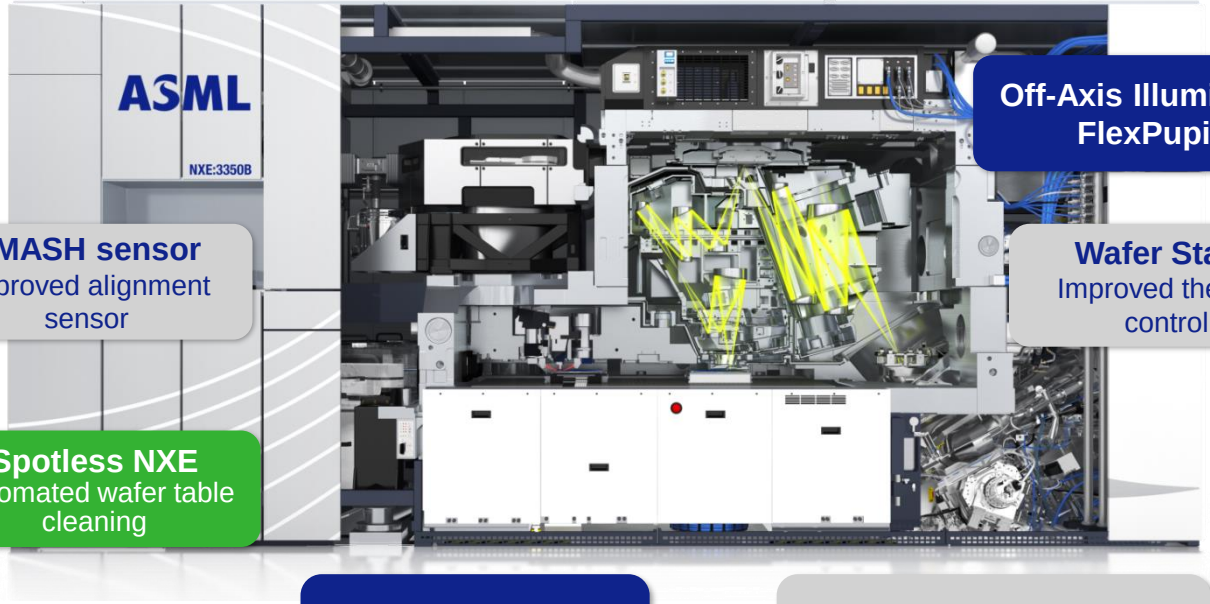
NXE:3350B: 2x overlay improvement at 16nm resolution

Supporting 7nm logic, ~15nm DRAM requirements

Overlay set up
Set-up and modeling improvements

Reticle Stage
Better thermal control increased servo bandwidth

Projection Optics
Higher lens transmission improved aberrations and distortion



Off-Axis Illuminator FlexPupil

SMASH sensor
Improved alignment sensor

Wafer Stage
Improved thermal control

Spotless NXE
Automated wafer table cleaning

New UV level sensor

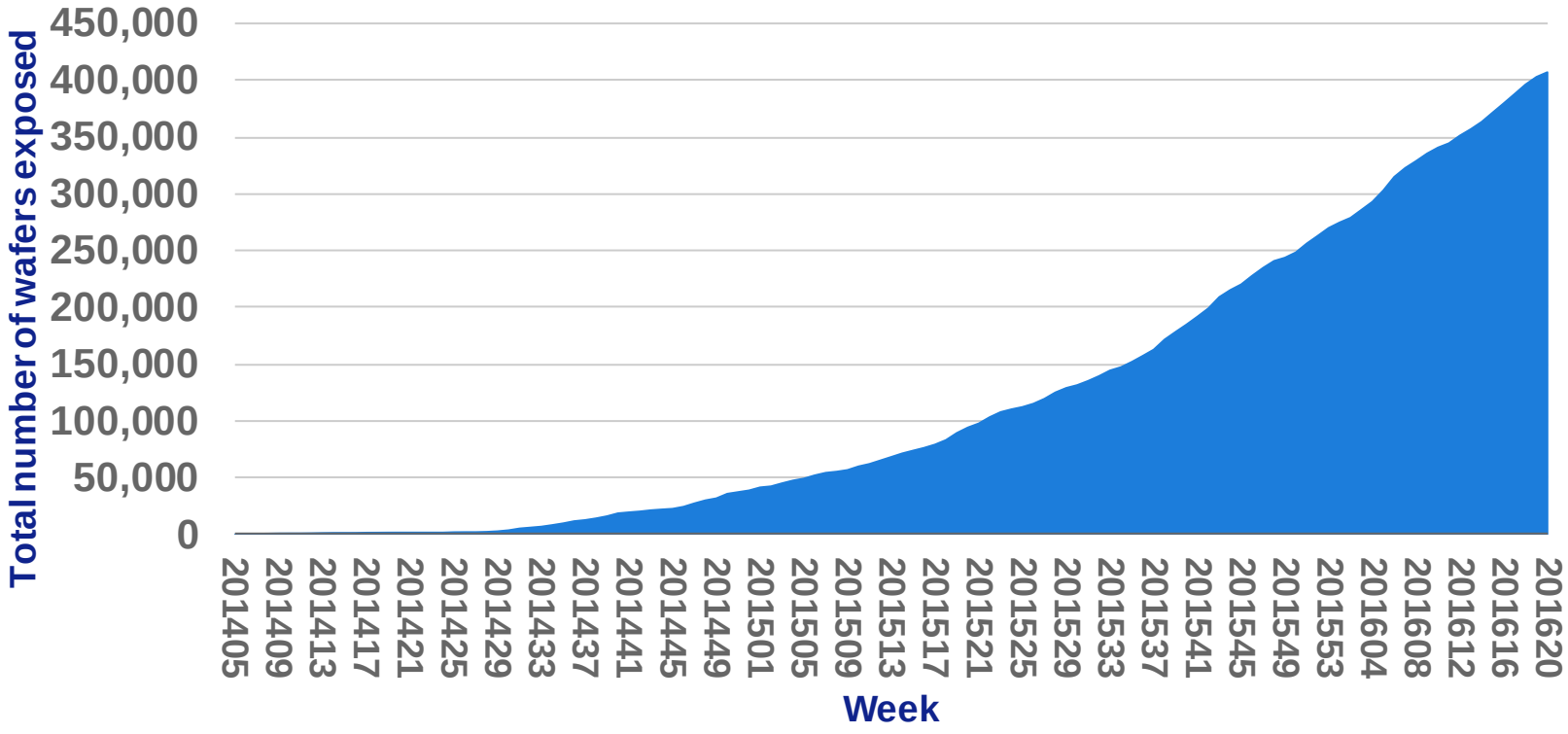
Improved air mounts

Resolution	16nm
Full wafer CDU	≤ 1.3nm
DCO	≤ 1.5nm
MMO	≤ 2.5nm
Focus control	≤ 70nm
Productivity	≥ 125 WPH

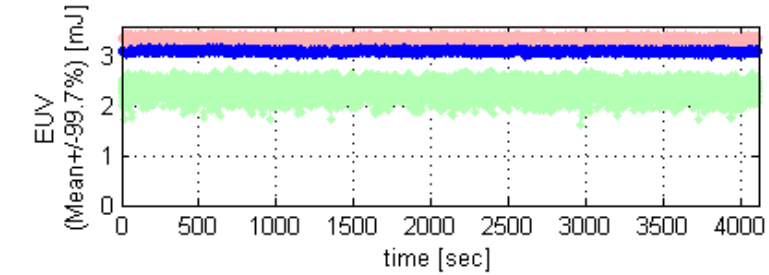
Overlay
Imaging/Focus
Productivity

>405k wafers exposed on NXE:3300B at customer sites

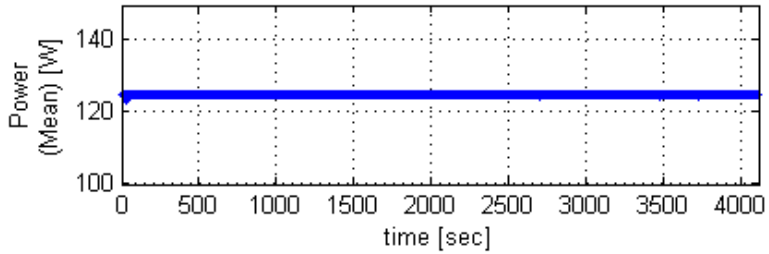
Currently 8 systems running in the field



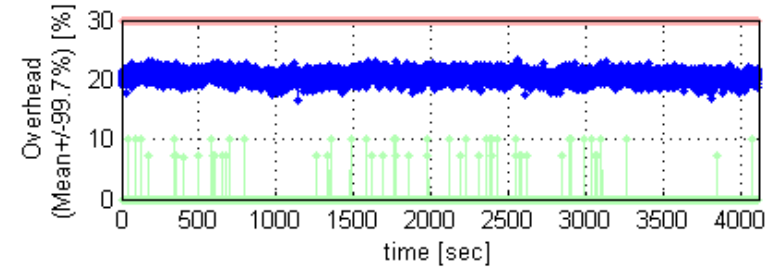
NXE:3350B: 125W settings qualified



Mean pulse energy at Intermediate Focus ~3mJ

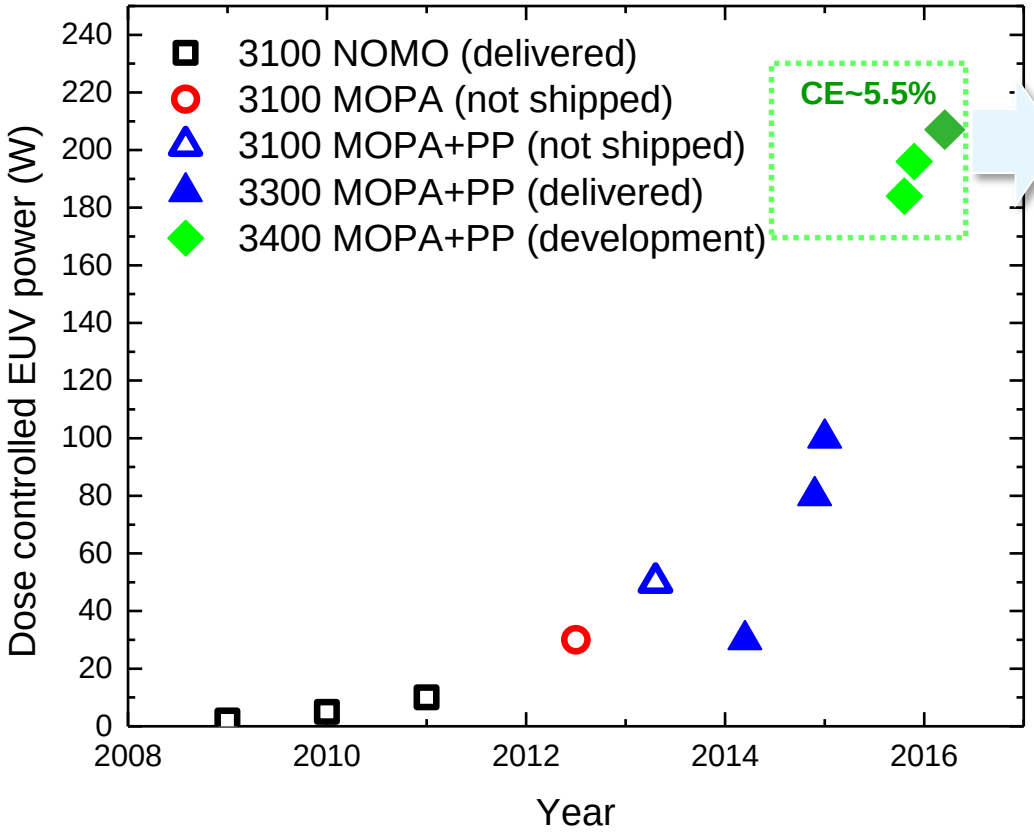


EUV power at Intermediate Focus 125W

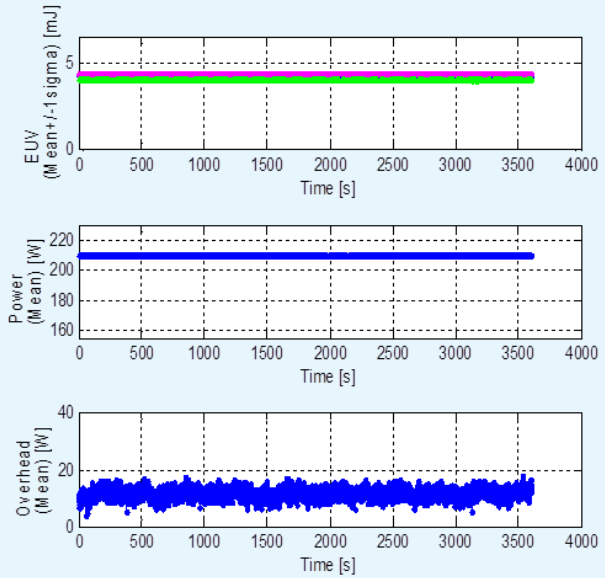


Energy control Overhead ~20%

Progress in source power supporting productivity roadmap to >125 WPH



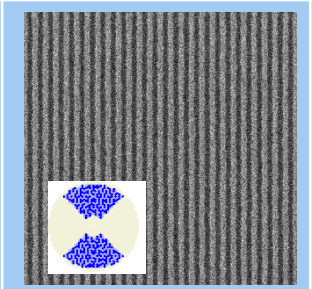
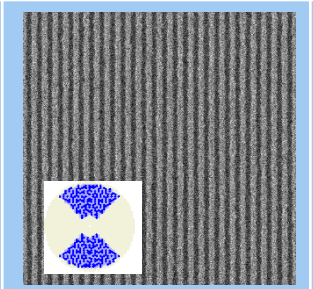
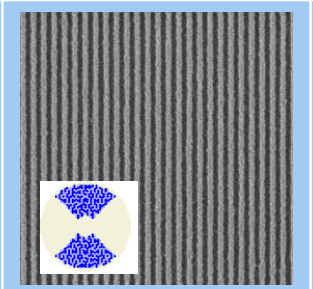
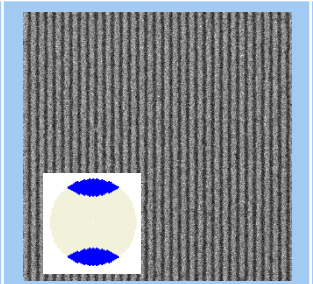
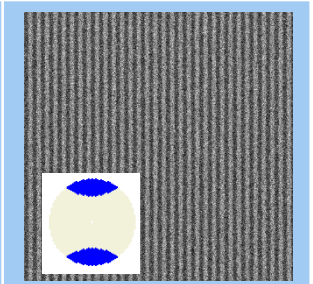
210W with dose in specifications obtained on development source



EUV – Installed Base: more than power alone

Process: resist towards 16nm resolution at 125 WPH

19% EL, 4.4nm LWR @18.5mJ/cm². Also 13nm resolved with 17% EL and 4.2nm LWR @31mJ/cm²

NXE:3350B	16nm Horizontal Dense lines/spaces			13nm Horizontal Dense lines/spaces	
	Reference CAR	New formulation CAR	New Inpria resist (NTI non-CAR)	CAR	New Inpria resist (NTI non-CAR)
SEM image @BE/BF					
Dose	40 mJ/cm²	25 mJ/cm²	**18.5 mJ/cm²**	~40 mJ/cm²	31 mJ/cm²
Exposure Latitude	16 %	16 %	19 %	-	17 %
DoF	145 nm	100 nm	125 nm	-	150 nm
LWR	4.6 nm	5.2 nm	4.4 nm	4.5 nm	4.2 nm

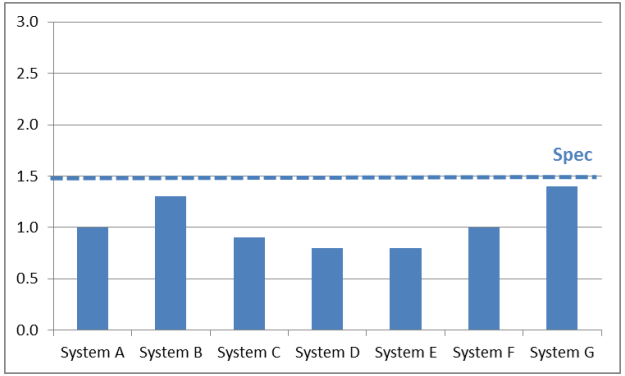
LWR = Line Width Roughness
DoF = Depth of Focus
EL = Exposure Latitude

BE/BF = Best Energy/Best Focus
CAR = Chemically Amplified Resist

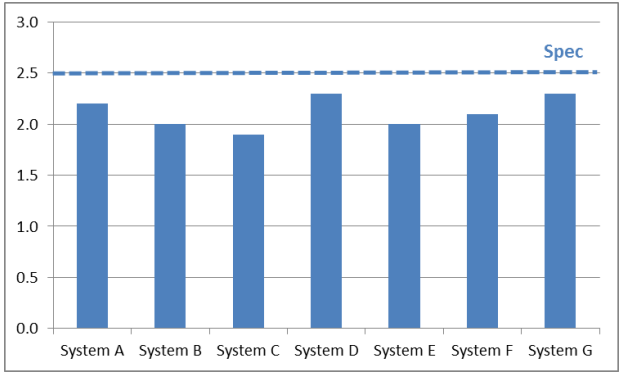
NXE:3350B **overlay** and **focus** performance

Well in specification due to HW improvement and new calibrations

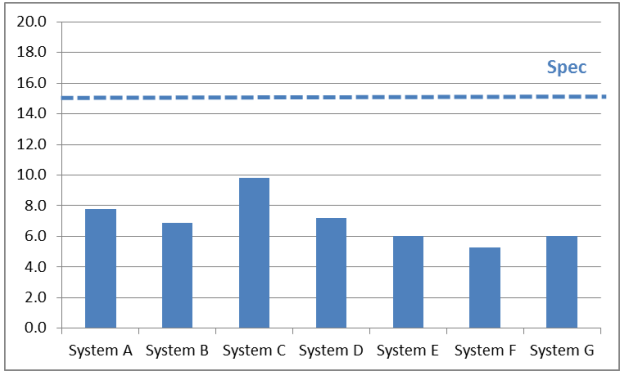
Dedicated chuck overlay [nm]

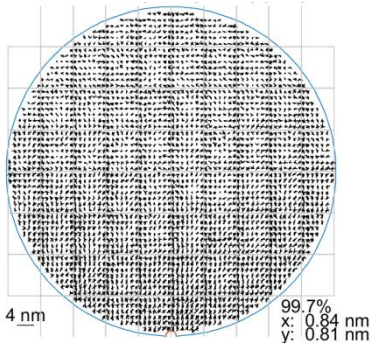


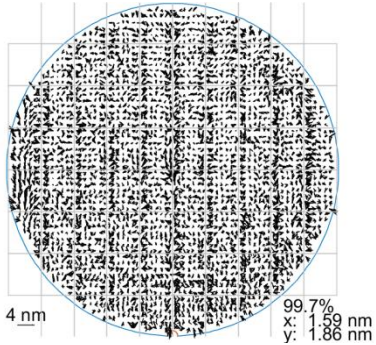
Matched machine overlay [nm]

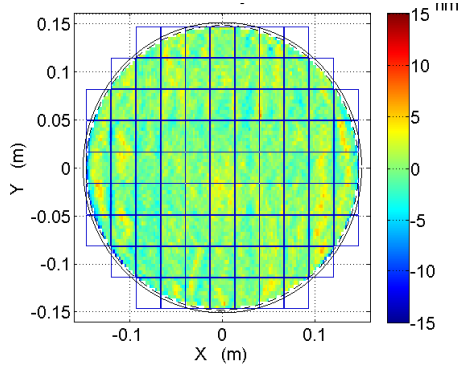


Focus uniformity [nm]

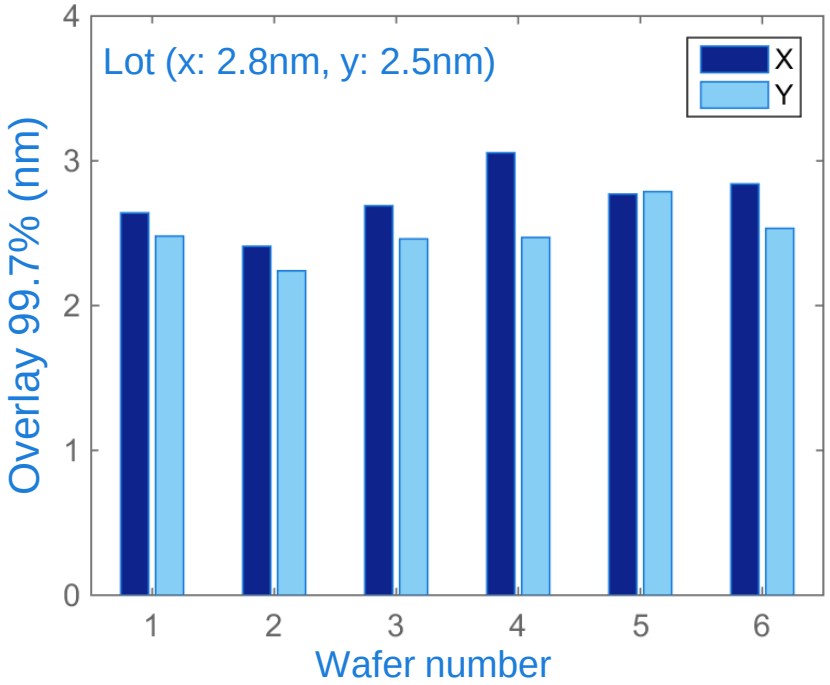


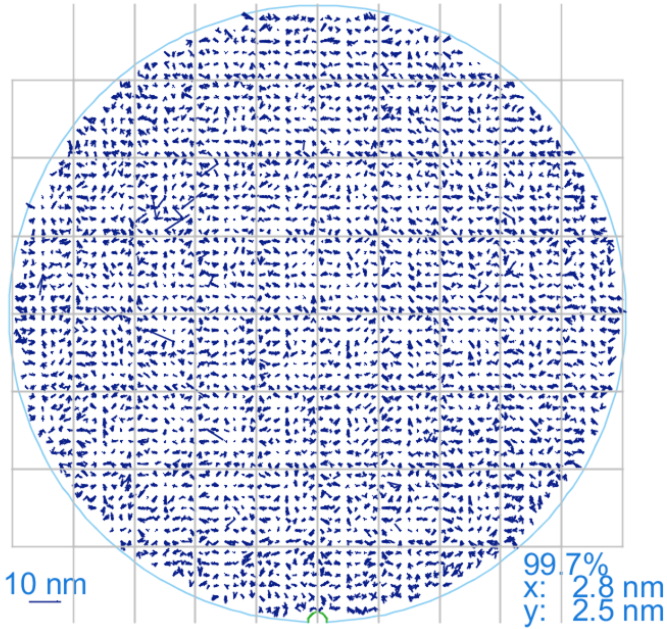




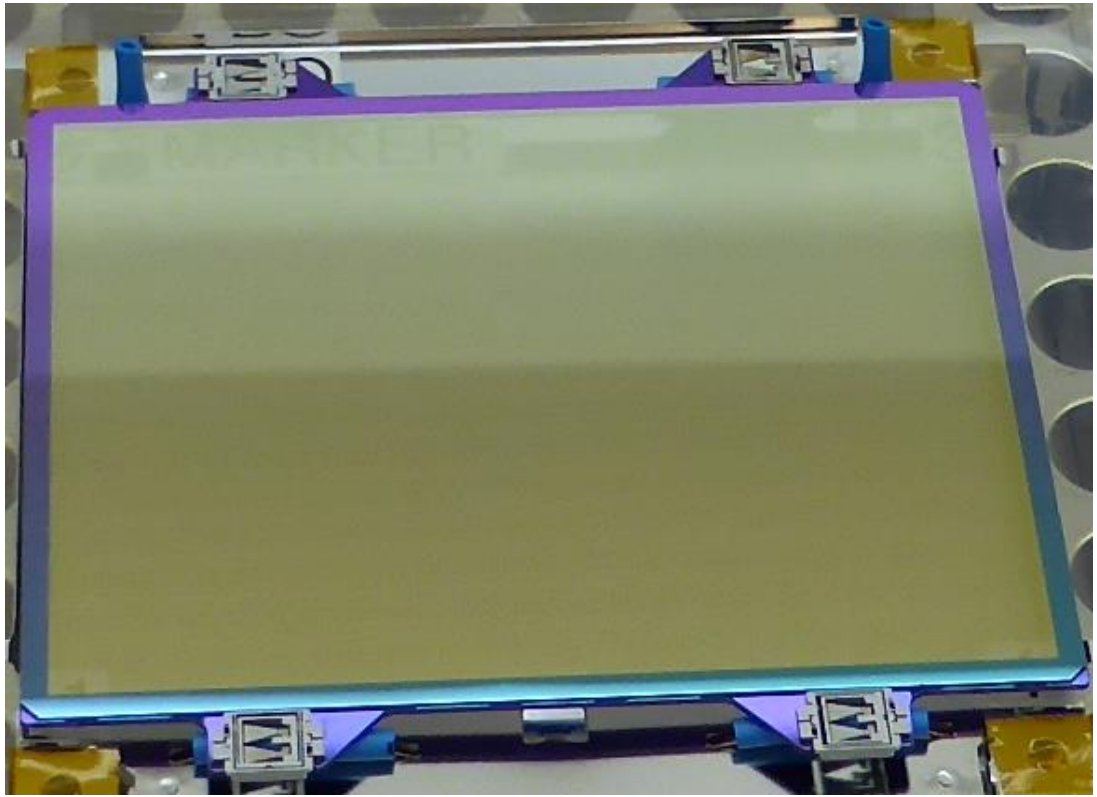


NXE:3350B **matched machine overlay** with NXT:1980Di <2.8nm





NXE Pellicles are being mounted and used in scanners

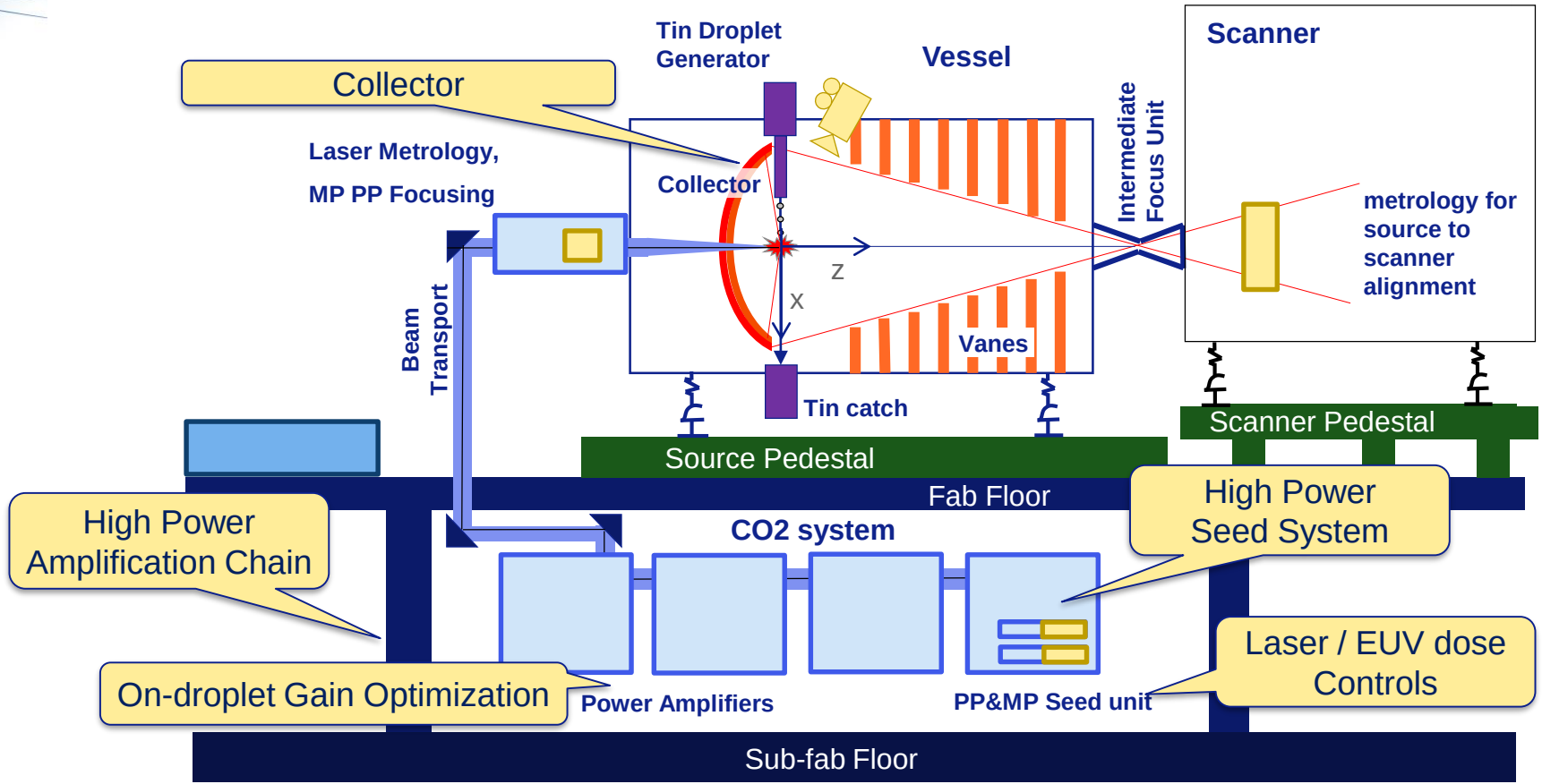


Prototype pellicle on early integration mounting tooling

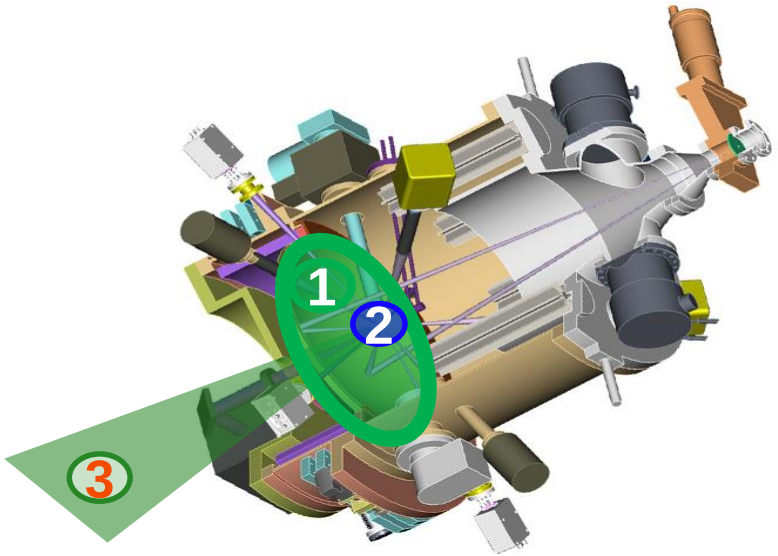
- **EUV source architecture, performance , power scaling**

  The beauty of the ASML/CYMER EUV Source

EUV Source Architecture, Sn LPP MOPA with Pre-pulse



EUV LPP Source Key Technologies



Optics Protection 1
(Debris Management)
- Collector protection by gas flow
- In-situ collector cleaning
- Collector capping layers

Availability / CoO

Targeting Dynamics 2
- Target conditioning
- Focus Control
- x,y,z, E & t control

Dose Control / Yield

CO_2 Laser Power 3
- High power drive laser

Conversion Efficiency
- Prepulse

EUV Power / Throughput

Source power and availability drive productivity

Technology development work is ongoing to improve all aspects

Productivity = Throughput($\propto$EUV Power) $\times$ Availability

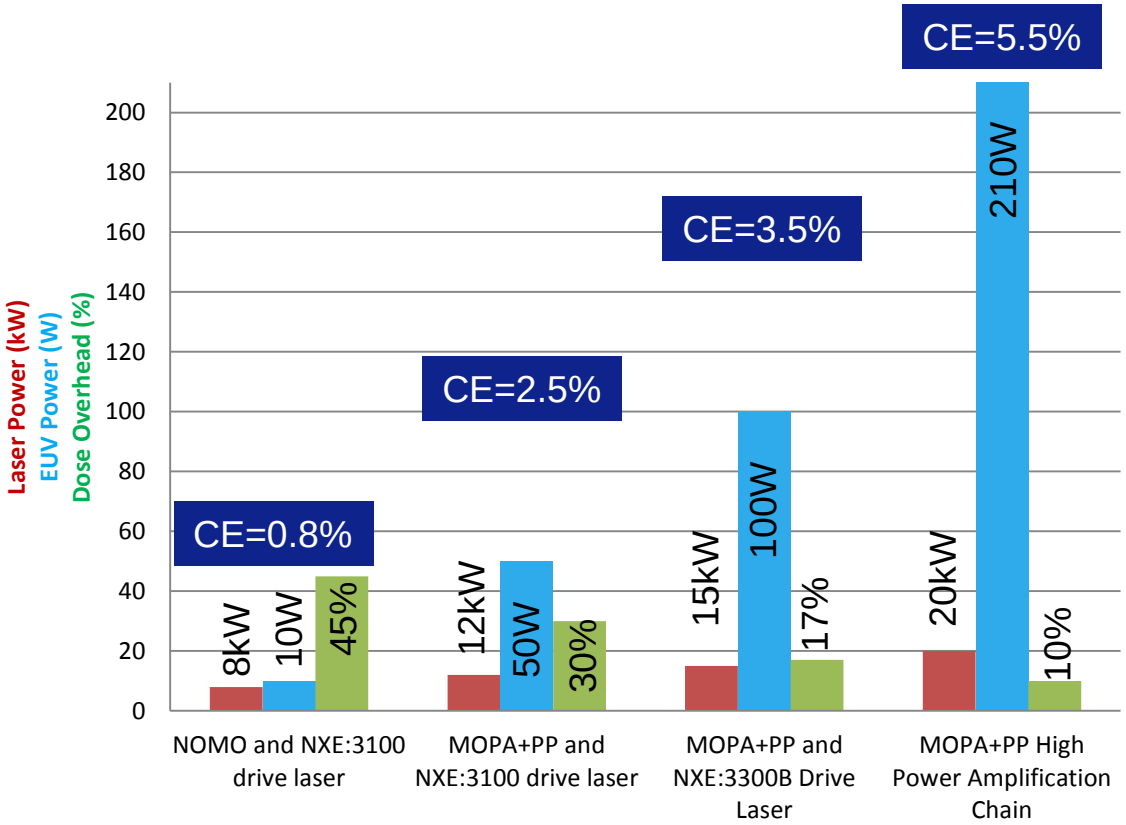
EUV Power= (CO_2 laser power $\times$ CE $\times$ transmission)*(1-dose overhead)

Raw EUV power

Source power **from 10 W to > 250 W**	Drive laser power	from 20 to 40 kW
	Conversion efficiency (CE)	from 1 to 6%
	Dose margin	from 50 to 10%
	Optical transmission	
Source availability	Automation	
	Collector protection	
	Droplet generator reliability & lifetime	
	Drive laser reliability	

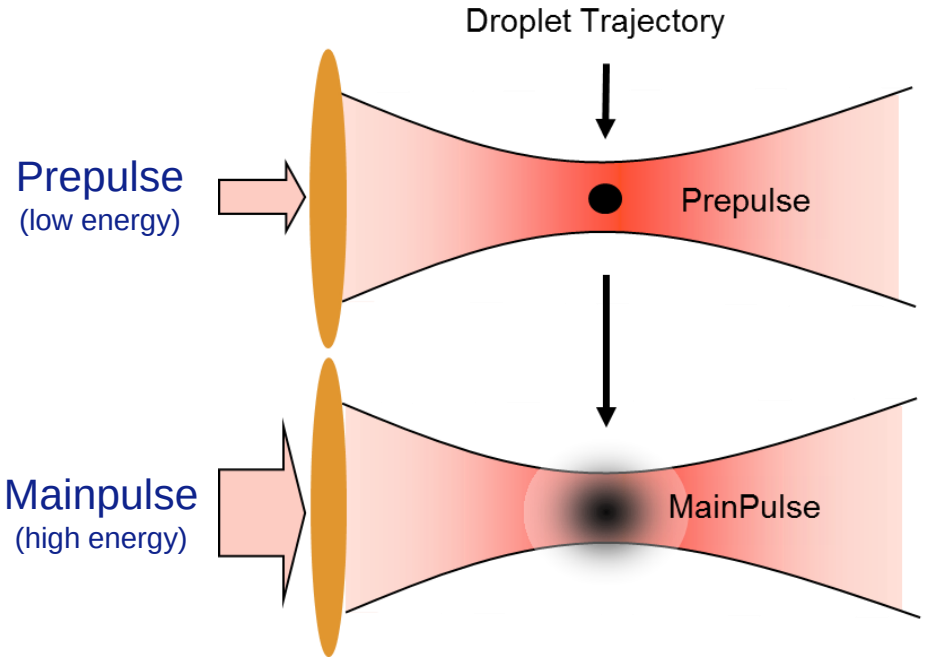
EUV power scaling through 2016

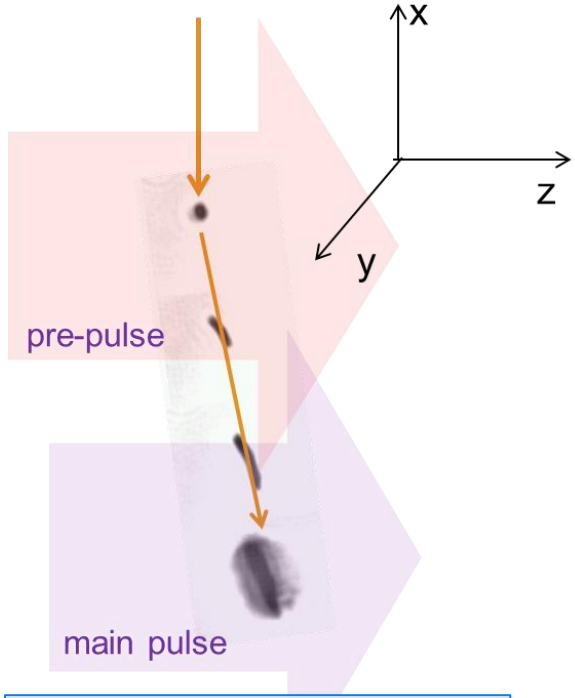
EUV power ~ CO_2 power * Conversion Efficiency * (1-Dose Overhead)



Conversion efficiency: Optimizing pre-pulse to create a

Target expansion fills main pulse beam waist

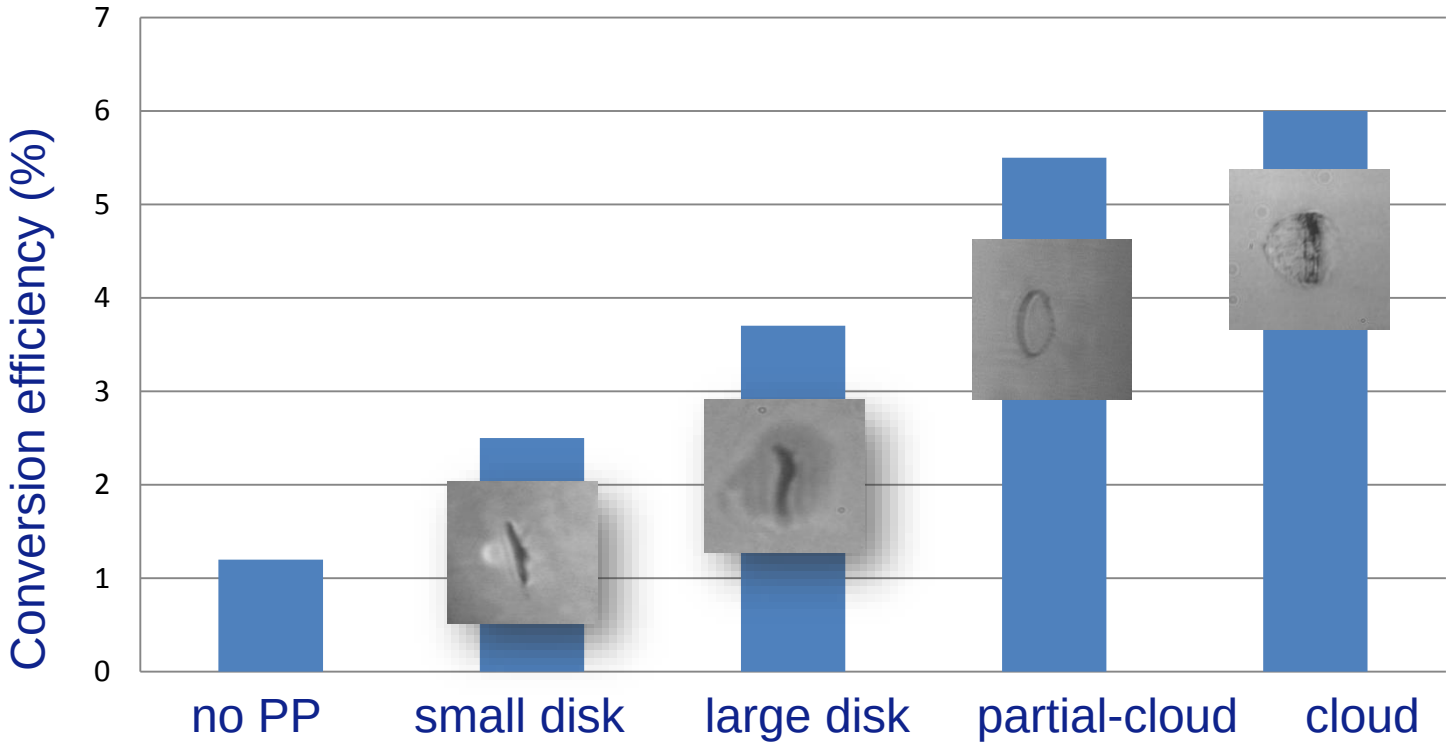




Target shape changes from droplet to disk

Increased conversion efficiency with Pre-pulse

by optimization of target size, shape and density

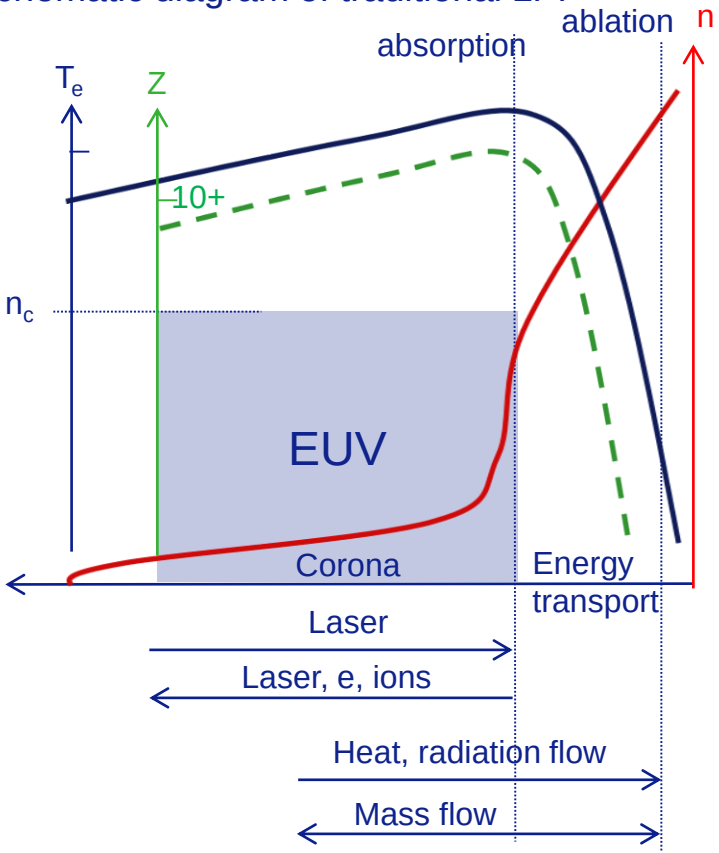


EUV CE ~6% demonstrated on development platforms

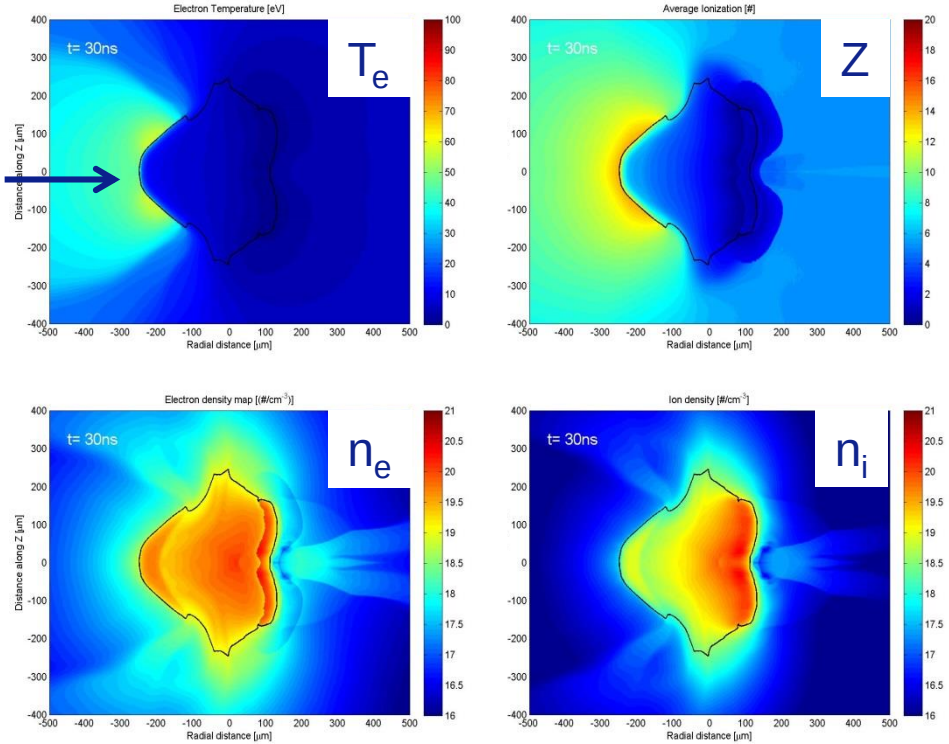
Plasma scale length (Z) is the key to increase its volume

Volume-distributed laser absorption enhances CO_2 laser deposition in plasma

Schematic diagram of traditional LPP



Hydrodynamic simulation of CO_2 Sn LPP



SPIE 2016, 97760K-1, Michael Purvis
"Advances in predictive plasma formation modelling"

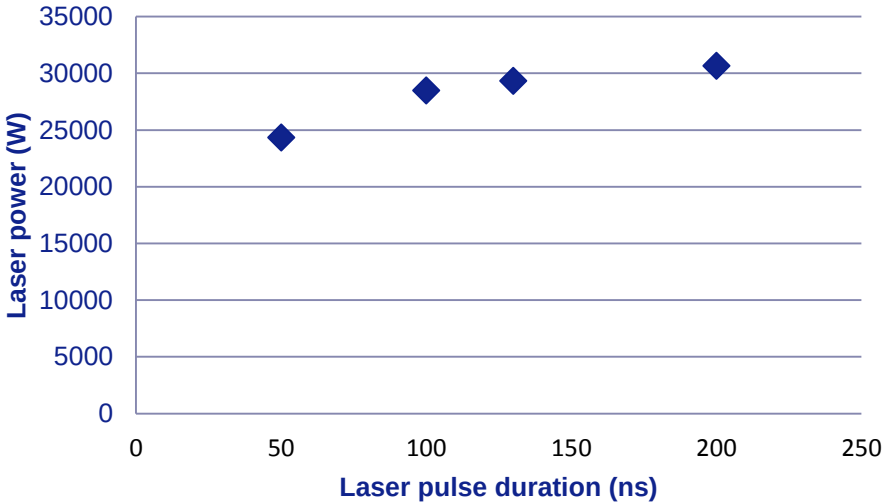
- **The Drive Laser, Droplet Generator And collector**

CO_2 laser power scaling to scale EUV power

Efficient CO_2 laser pulse amplification

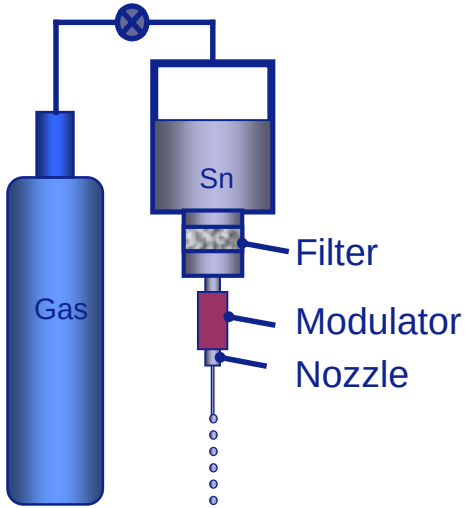
Throughput, WPH	125	145	185
EUV power (W)	250	350	500
CO_2 lase power (kW)	27	30	40

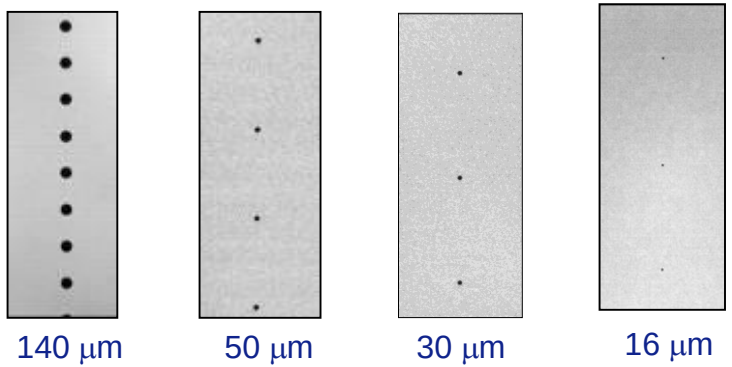
3300 CO_2 drive laser

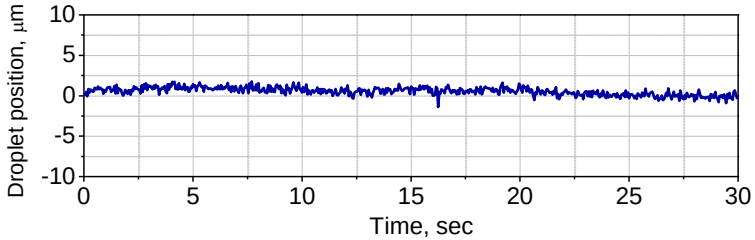


Droplet Generator, Principle of Operation

- Tin is loaded in a vessel & heated above melting point
- Pressure applied by an inert gas
- Tin flows through a filter prior to the nozzle
- Tin jet is modulated by mechanical vibrations

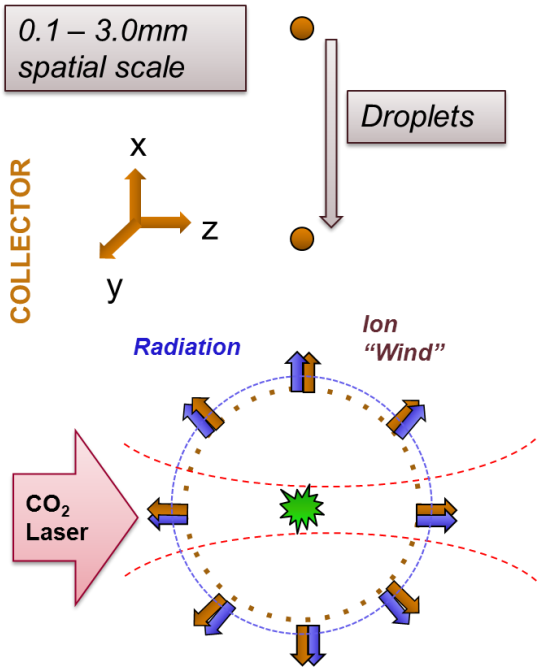






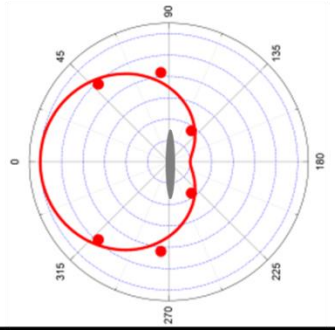
Short term droplet position stability σ~1μm

Forces on Droplets during EUV Generation



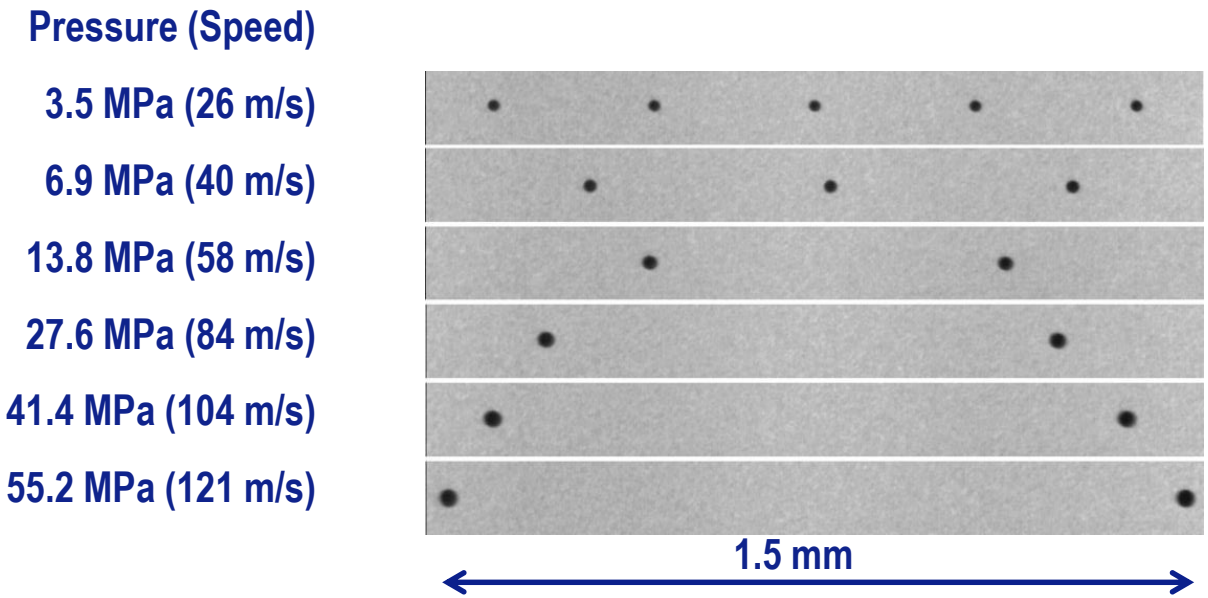
Measured Angular dependence of Forces on the droplets

Function fit: Force ~ EUVen *A*(1+cosθ+B) / R^2



High EUV power at high repetition rates drives requirements for higher speed droplets with large space between droplets

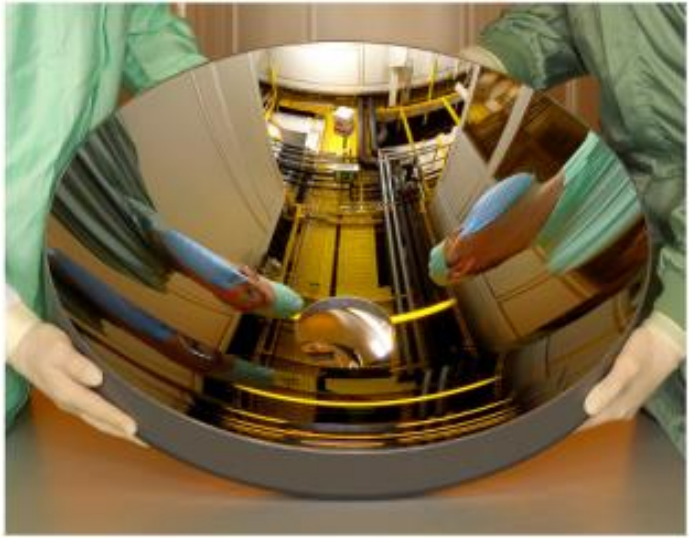
High Speed Droplet Generation



Tin droplets at 80 kHz and at different applied pressures.
Images taken at a distance of 200 mm from the nozzle

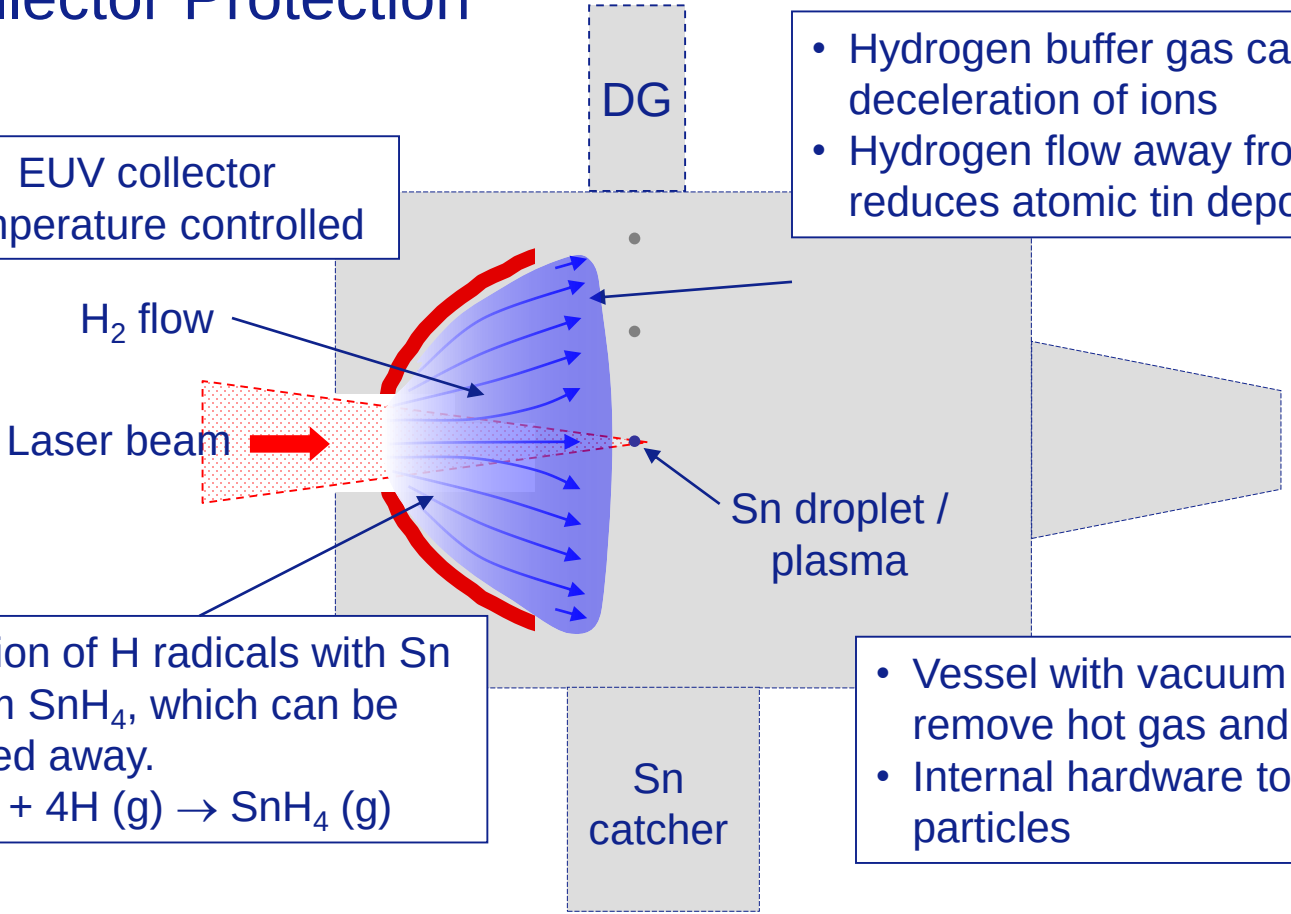
EUV Collector: Normal Incidence

- Ellipsoidal design
  - Plasma at first focus
  - Power delivered to exposure tool at second focus (intermediate focus)
- 650 mm diameter
- Collection solid angle: 5 sterrad
- Average reflectivity: > 40%
- Wavelength matching across the entire collection area



5sr Normal Incidence Graded Multilayer Coated Collector

Collector Protection



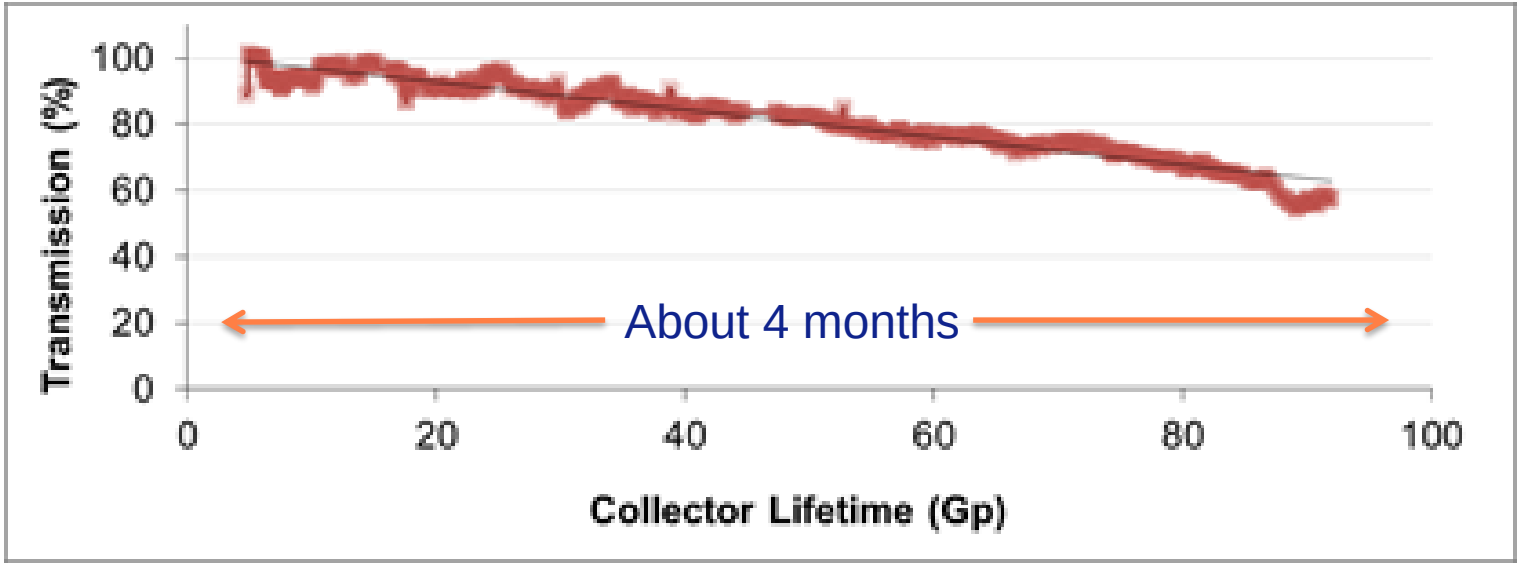
- Hydrogen buffer gas causes deceleration of ions
- Hydrogen flow away from collector reduces atomic tin deposition rate

Reaction of H radicals with Sn to form SnH_4, which can be pumped away.
$Sn\ (s) + 4H\ (g) \rightarrow SnH_4\ (g)$

- Vessel with vacuum pumping to remove hot gas and tin vapor
- Internal hardware to collect micro particles

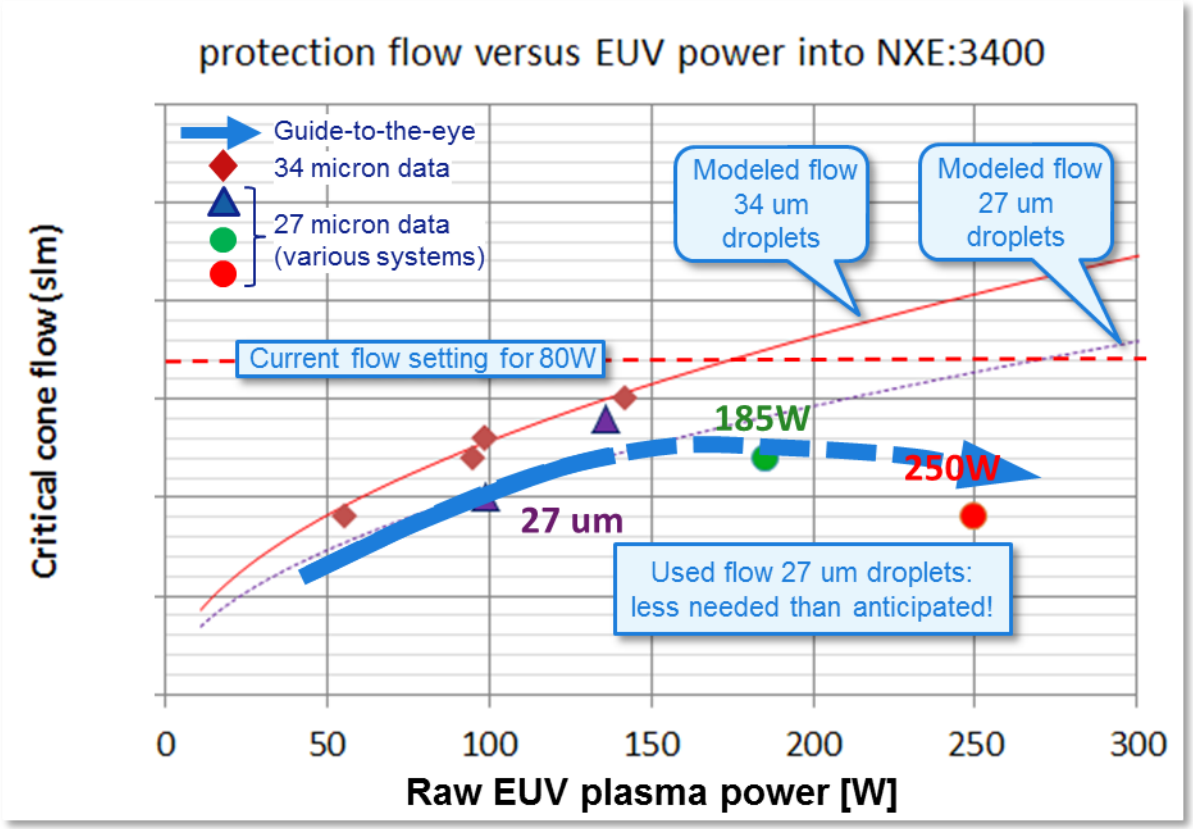
Collector Lifetime on NXE

-0.4%/Gp: observed at a customer

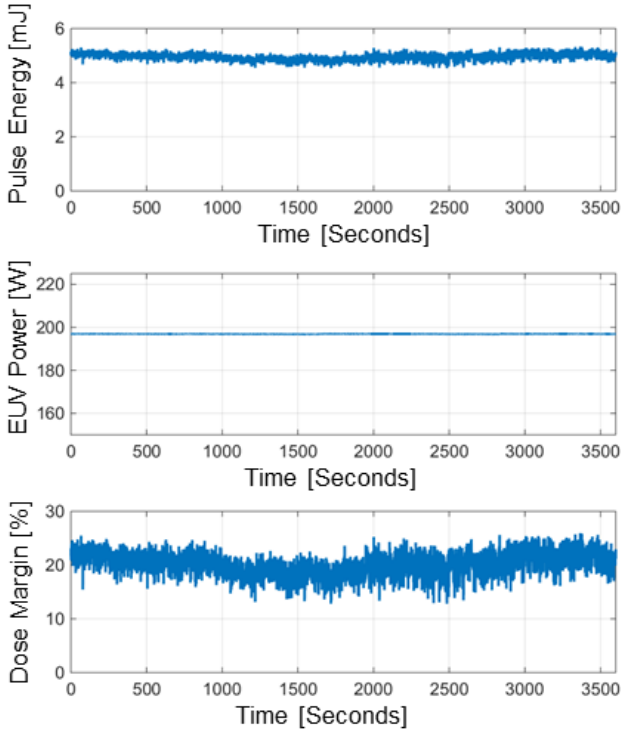


250W feasibility proven without increase in protective Hydrogen flow

No rapid collector contamination, allowing stable droplets and >125 w/hr@20 mJ/cm²



~200W dose controlled power



Summary

Significant progress in EUV power scaling,

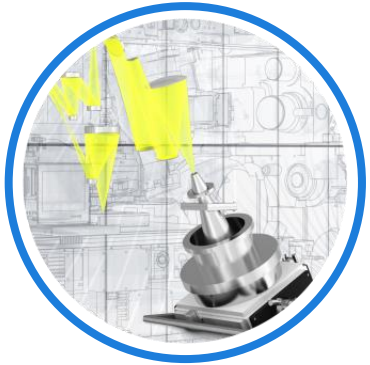
- CE is up to 6 %
- Dose-controlled power is up to 210 W

CO_2 developments support EUV power scaling,

- Clean (spatial and temporal) amplification of short CO_2 laser pulse
- High power seed-table enables CO_2 laser power scaling

Significant progress made in Source Availability

- >80% source availability in the field
- >1000 hrs droplet generator runtime
- >100 Gp collector lifetime



Acknowledgements:


ASML
CYMER
An ASML company